Overview of the ICESat Mission

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[1] The Geoscience Laser Altimeter System (GLAS) on the NASA Ice, Cloud and land Elevation Satellite (ICESat) has provided a view of the Earth in three dimensions with unprecedented accuracy. Although the primary objectives focus on polar ice sheet mass balance, the GLAS measurements, distributed in 15 science data products, have interdisciplinary application to land topography, hydrology, vegetation canopy heights, cloud heights and atmospheric aerosol distributions. Early laser life issues have been mitigated with the adoption of 33-day operation periods, three times per year, designed to document intra- and inter-annual polar ice changes in accordance with mission requirements. A variety of calibration/validation experiments have been executed which show that the elevation products, when fully calibrated, have an accuracy that meets the science requirements. The series of papers in this special ICESat issue demonstrate the utility and quality of the ICESat data. **Citation:** Schutz, B. E., H. J. Zwally, C. A. Shuman, D. Hancock, and J. P. DiMarzio (2005), Overview of the ICESat Mission, *Geophys. Res. Lett.*, *32*, L21S01, doi:10.1029/2005GL024009.

1. ICESat Mission Science Objectives and Requirements

[2] The primary purpose of ICESat is the determination of inter-annual and long-term changes in polar ice-sheet volume (and inferred mass change) to sufficient accuracy to assess their impact on global sea level [*Zwally et al.*, 2002]. A specific objective of ICESat is to reduce the uncertainty in the known ice sheet mass balance through determination of polar ice elevation change with better than 2 cm/yr accuracy over 100 km × 100 km areas, averaged over three or more years of seasonal and interannual variability. To achieve this objective, ICESat has utilized narrow beam laser altimetry, with state-of-the art instrumentation, to determine the geodetic coordinates of a series of points on the ice sheet with vertical accuracy at the decimeter level. Although ICESat has been designed to meet the demanding requirements of cryosphere applications, its design supports numerous multidisciplinary applications.

2. Measurement Concept and Implementation

[3] The elevation of a spot on the Earth's surface illuminated by a spaceborne laser is determined from the sum of two vectors: the position vector of the laser instrument plus the range vector (the position vector of the illuminated spot centroid with respect to the instrument, alternatively referred to as the altitude vector). The resultant vector is the position of the spot (or footprint), which can be readily transformed into geodetic latitude, longitude and height (or elevation) with respect to a reference ellipsoid. The fundamental data product consists of this geolocated spot and its surface arrival time (time tag).

[4] This measurement concept was implemented on ICESat using GLAS, which was designed, constructed and tested at NASA Goddard Space Flight Center (GSFC) to meet the science requirements. Ball Aerospace Corporation built the spacecraft bus to provide a source of power, communication and on-orbit command and control. The combined GLAS and spacecraft bus are collectively known as ICESat. In the ICESat terminology, altimetry is used for range measurements to the Earth's surface, whereas lidar is used for measurements related to laser backscattering within the atmosphere.

[5] GLAS has three lasers (designated Laser 1, 2 and 3) mounted on a rigid optical bench, with only one laser operating at a time [*Zwally et al.*, 2002; *Abshire et al.*, 2005]. Each laser produces a 1064 nm pulse for altimetry and lidar, but a doubler crystal produces a 532 nm wavelength pulse, which yields a more sensitive determination of the vertical distribution of clouds and aerosols [*Spinhirne et al.*, 2005]. The operating laser pulses at 40 Hz and the transmitted laser pulse illuminates a spot on the Earth's surface with a diameter of ~65 m, except when optically thick clouds obscure the surface. Successive spots are separated on the Earth's surface by 172 m. The laser pulse is also referred to as the laser shot. The echo pulse is captured by a 1 m diameter telescope and directed to an analog detector, then digitized by a 1 GHz sampler, along with a digitized record of the transmit pulse. Each pair of digitized transmit and corresponding echo pulses is telemetered to the ground for analysis. These digitized pulses are referred to as laser waveforms. From the waveform data, the transmit time and the echo receive time are determined, from which the pulse time of flight (TOF) is computed. The one-way range, or magnitude of the range vector, is half the TOF multiplied by the speed of light. In addition, this one-way range is subjected to corrections, such as propagation delay in the troposphere.

[6] During the 4 ms pulse TOF from ICESat, the digitizer creates 4 million samples, starting just before the transmit pulse. GLAS on-board processing identifies the transmit and the echo pulses in the 4 ms record for telemetering to the ground. The on-board search for a valid echo pulse uses a 1° × 1° digital elevation model, with surface type, and

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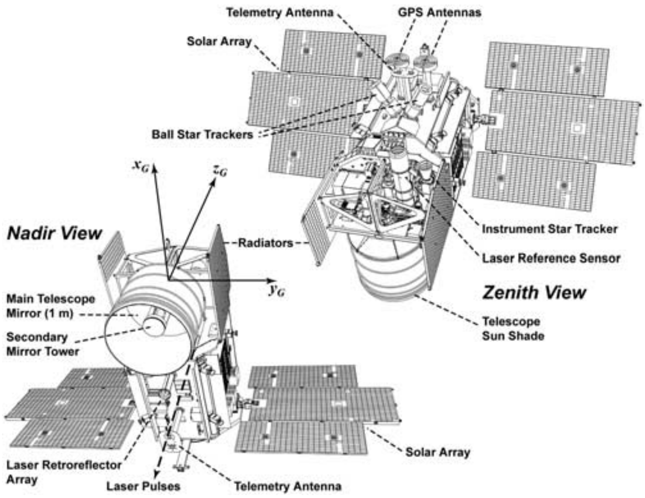

Figure 1. ICESat nadir (Earth-facing) and zenith views. Thrusters used for orbit modification are located on the far side (not shown) opposite the GLAS telescope.

real-time ICESat position to estimate the expected TOF. For the implemented surface types of ice and land, there are 544 samples (or bins), whereas sea ice and water uses 200 bins. The effective one-way distance associated with 544 bins is 81.6 m and 30 m for 200 bins, which represents the maximum elevation change within a single spot that can be recorded.

[7] The direction of the range vector from ICESat/GLAS (Figure 1) is obtained using an Instrument Star Tracker (IST) with an 8° field of view (FOV) and Hemispherical Resonator Gyroscopes (HRG). The process by which the orientation, or attitude, of the GLAS optical bench is determined is referred to as Precision Attitude Determination (PAD), but the actual result yields the laser path orientation in space. The instrumentation is described by M. Sirota et al. (The transmitter pointing determination in the Geoscience Laser Altimeter System, submitted to *Geophysical Research Letters*, 2005, hereinafter referred to as Sirota et al., submitted manuscript, 2005). The Laser Reference Sensor (LRS) images the transmitted laser far-field, as well as an optical source mounted on the IST (Collimated Reference Source, CRS) and stars that appear in its 0.5° FOV. The CRS is based on the 532 nm pulse. The IST and LRS operate at 10 Hz, but an additional camera (Laser Profile Array, LPA) images the far-field pattern of each laser shot at 40 Hz.

[8] Prelaunch calibration measurements were made to determine the reference location for range measurements made by GLAS. The physical location of the GLAS reference point for range measurements is on the optical bench, located near the center of the telescope. The measurement of the laser transmit direction with respect to the optical bench could not be made in the laboratory. As a consequence, the LRS and on-orbit calibration experiments were designed to enable that determination after launch.

[9] The determination of the position of the GLAS reference point in space is made using the GPS tracking system. This process is referred to as Precision Orbit Determination (POD). Two JPL BlackJack receiver/antenna combinations are available for redundancy, but only one receiver has been used to date. The POD methodology uses data provided by the International GPS Service and the International Earth Rotation Service. A laser retroreflector array (LRA) on the nadir side supports ranging from the collaborating stations of the International Laser Ranging Service and although these data are withheld from the POD process, they are used to assess the accuracy of the GPS-derived POD.

3. Mission Description

[10] ICESat was launched on a Delta-2 rocket from Vandenberg AFB at 0045 UT on January 13, 2002, into a 600 km altitude orbit with a 94° inclination. The inclination was chosen to provide coverage of changing ice features in West Antarctica allow comparison of derived elevations at crossover points (intersections between ascending and descending tracks) that are commonly used in altimeter analyses. The orbit is maintained with approximately 10-day maneuvers to compensate for natural orbit decay in order to produce a ground track that is always close (±1 km at the equator) to an ideal, exact repeat track, referred to as the reference track. Two reference orbits (or tracks) have been used by the mission (Table 1): an 8-day exact repeat and a 91-day exact repeat (with a 33 day sub-cycle). The 8-day interval was adopted to enable frequent repeats of ground calibration sites and the longer interval was adopted to provide denser track coverage for science applications.

[11] The normal spatial orientation of ICESat can be described with the axes shown in Figure 1. The minus-z_G axis is 0.3° from geodetic nadir (i.e., perpendicular to the Earth ellipsoid). Two basic ICESat orientations (attitude) are used to take best advantage of the Sun geometry. In the sailboat (SB) mode, the y_G axis (plus or minus) is closely coincident with the satellite velocity vector. In the airplane (AP) mode, the x_G axis (plus or minus) is closely aligned with the velocity vector. A specific attitude mode is used continuously for approximately six months. The 0.3° off-nadir angle is a fixed rotation of the spacecraft away from the Earth (a "pitch-up") by this angle about an axis approximately perpendicular to the velocity vector to mitigate detector damage from specular reflections of laser pulses from mirror-like surfaces (e.g., still water).

6. Summary

[25] The ICESat mission is Earth's first polar orbiting satellite to carry a laser altimeter, and it continues to provide surface elevation of the ice sheets and other surfaces, with unprecedented accuracy and along-track resolution. The global data products offer a diverse and scientifically rich data set for multidisciplinary applications. Although instrumental issues have delayed the completion of full calibrations of the elevation products, the full set of data is being reprocessed with the goal of reaching the high accuracy exhibited by the Laser 2a Release 21, now available at NSIDC.